Enabling IEEE 802.21 in a B3G Cellular Experimental Network

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Abstract: Recent trends in mobile networking show the large scale emergence of multimode mobile terminals, with the capability to simultaneously or sequentially attach to conceptually different access networks. To cope with this, they require an abstracted framework for mobility management and control. A solution to this issue, called Media Independent Handover Services, is standardized by the 802.21 group of the IEEE. This work has been studied and applied to the case of a B3G operator networks in an EU-funded research project in order to improve seamless handover between heterogeneous technologies. This paper focuses on the integration of the Beyond-3G cellular access technology in this framework, and how it can cooperate with the 802.21 to execute handovers to and from cellular networks. This study has been implemented in an experimental software radio platform which provides a direct inter-connection between the access node and the IPv6 Core Network, very close to the LTE specifications of the 3GPP. We describe here the mapping between a selection of Media Independent Handover primitives and the cellular air interface procedures available in the platform for Mobility, Quality of Service management and Multicast support (MBMS). Finally, we provide some measurements and results obtained after the integration and demonstration of the heterogeneous network framework.

Keywords: MIH, B3G, LTE, UMTS, IEEE 802.21, Handover, QoS, Heterogeneous networks.

1. Introduction

Recent years have seen the explosion of mobile communications, together with an exponential use of the Internet for all sorts of applications such as voice calls, video conferencing or Mobile TV. As a consequence, the trend in the mobile technologies has been the conception of multimode devices, with an increasing number of interfaces, at the centre of fixed and mobile or telecom and broadcasting convergence.

Building and operating such devices can become very complex if each access technology has to be addressed directly and separately by the control entities in the device and in the network. It becomes even worse in the case of handovers between varied accesses, because this requires a certain degree of synchronization across the different technologies. To address this issue, the IEEE 802.21 work group [1] has standardized a handoff process common to all the 802 media and that tentatively enables the mobility to and from 3G cellular systems. However, the cellular architecture is conceptually very different from that of 802.x technologies, which brings an increased level of complexity. One of the EU (European Union)-funded research projects, Daidalos, has considered this issue of heterogeneous access networks. The cellular or UMTS (Universal Mobile Terrestrial Service) access is provided by an experimental software radio platform which features a direct-interconnection between the IP protocol and the UMTS air interface, and in that sense offers an IP connectivity close to that of the LTE (3GPP Long Term Evolution) model. This paper describes how this technology has been integrated in the abstract architecture inspired from the work of the 802.21 group. This description is followed by the presentation and analysis of the measurements and results obtained at the project testbed with a real-time implementation of this study.

This paper is organized as follows. Section 2 describes the experimental platform and its direct interconnection between IP and LTE-like UMTS. Continuing with the related work, two architectures for abstracting access technologies that were designed in parallel are introduced in section 3, first our initial basic and proprietary architecture, then the 802.21 standard. Section 4 presents the work performed to enable Media Independent Handover with the cellular access, while section 5 focuses on the issue of an extension for the dynamic allocation of radio resources, and the support of some Media Independent Quality of Service. The implementation measurements and results from the full-scale testbed are presented in section 6 and finally, we draw our conclusions in section 7.

2. Experimental Software Radio Platform Description

This experimental Software Radio Platform can be used in Beyond-3G (B3G) wireless network experimentations [2]. The cellular version described here is derived from the UMTS standard from the 3GPP [3]. The hardware architecture is based on a PC system complemented by a RF (Radio Frequency) module. The software part is an extension to the Linux Operating System and makes use of a hard real-time micro-kernel. It contains all the protocols needed to operate the air interface.

The Layer 2+ of the air interface protocol stack deviates from the 3GPP in the sense that it provides a direct interconnection with an IPv6 network in the Access Router (AR). Running IP up to the AR impacts the network architecture of the system, since it bypasses the UMTS-specific entities of the Core Network. The IP and IPv6 functionalities replace the mobility, security and Quality of Service (QoS) management. A cell is considered as an IPv6 subnet, with its own prefix, under control of the AR. This allows seamless network operation between various access technologies, in particular between UMTS and WLAN (Wireless Local Area Network, IEEE 802.11), as shown in Figure 1. The major advantage relies in the data plane, where packets are directly routed through some standard and inexpensive IPv6 routing in the AR. The benefits are the avoidance of a non optimal “IP-in-IP” encapsulation, taking full advantage of the IPv6 enhancements, and a simplified deployment and management for the operator of a heterogeneous network offering several access technologies.

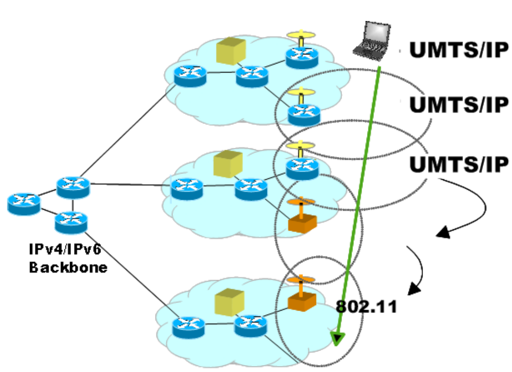

Figure 1: Platform seamless operation

In the Access Router and the Mobile Terminal (MT), the direct interconnection between the UMTS air interface and the IPv6 protocol is achieved by an inter-working middleware operating under the Linux IP protocol stack, as described in [2]. The platform is completed by a UMTS Access Stratum [3] protocol stack, mostly compliant with the 3GPP specifications, except for the Radio Resource Control (RRC) which has been adapted to the IPv6 direct interconnection. This architecture simplifies the model of an UMTS access, and is closer to the current LTE version of the 3GPP standards. Procedures take advantage of the IP protocol functionalities, the major part of the air interface control takes place in the E-UTRAN (Evolved Universal Terrestrial Radio Access Network), the number of bearers for transporting the IP data traffic has been reduced to a unitary radio bearer (or radio channel), and finally the protocols have been simplified to improve the performance and operation delays.

3. Abstracting Access Technologies

3.1 – Initial architecture for access technology abstraction

One of the projects taking advantage of this platform is Daidalos [4], an Integrated research Project under the EU’s Sixth Framework Program (FP6). In its first phase in the early 2004, it considered a generic architecture allowing a terminal to be connected simultaneously to several access technologies and execute seamless handovers. This has been described in [5]. A decoupling approach has been followed in order to ease the process of incorporating any future evolution of these technologies.

The global model is split into two main sub-layers. Each radio technology is controlled by a specific module, the Radio Access Layer (RAL). The Interface Abstraction Layer (IAL) is common to all the access technologies and harmonizes the radio control of the wireless technologies. It hides the nature of the access technologies to the Upper Layers. It maintains the information about the current activated interfaces and the Link Layer Identifier of the selected Base Station (BS). When it receives a message from the Upper Layers, it first determines the destination radio technology and then forwards the message to the corresponding RAL. It merges the measurements of QoS parameters at the radio interfaces from all the active RALs into a single report. The RALs are the components responsible for the specificities of each access technology, mostly in charge of reporting the measurements and executing the interface activation and deactivation on request. Three technologies were considered, WLAN, UMTS and DVB (Digital Video Broadcast), with a RAL each.

3.2 – The IEEE 802.21 standard

In March 2004, the IEEE formed the 802.21 working group with the goal to develop a standard to allow a mobile terminal to seamlessly roam across different types of 802.x network access technologies. The standard was named Media Independent Handover (MIH) Services [1] and was later extended to allow the integration of different cellular networks based on 3GPP and 3GPP2 specifications. The reasons for introducing this group were mostly that 802.x standards enable handover only to the same network types and behind the same router. In addition, Layer-3 mobility protocols like Mobile IP need acceleration for obtaining technology-independent triggers for the handover and for selecting the optimal candidate access points. The standard was designed to facilitate mobility related operations by providing a standardized, technology-independent interface just below the network layer of the ISO/OSI stack and above technology dependent data link and physical layers.

In order to help upper layer mobility management protocols, the 802.21 defines three different Media Independent Services which offer the generic triggers, information and tools needed to perform both Mobile Initiated Handovers (MIHO) and Network Initiated Handovers (NIHO). The Event Service provides the framework needed to manage the event classification, filtering, triggering and the reporting of dynamic changes in the different links, all these important to detect the optimal time for a handover. The Command Service allows the mobility management entities to control the different link behaviours and, in case of a handover, relay the information between the mobile terminal and the network. The Information Service is responsible of distributing technology-independent, topology related information to the mobile terminals in order to allow them to perform a handover with the maximum of information available.

The architecture proposed by the 802.21 revolves mostly around a logical component that provides these services to the other functions and modules running in a mobile terminal, the Media Independent Handover Function (MIHF). Inside the MT, a 3-layered architecture is defined and there the MIHF acts as a relay between the media-specific Link layer entities connected by the MIH_Link_SAP (Service Access Point) and the media-agnostic MIH-Users, or upper layer entities, connected over the MIH_SAP, responsible for handling mobility protocols operation, handover policies enforcing and application specific requests.

This kind of deployment makes it easy for MTs to roam between different Points of Attachment (PoAs) since the MIHFs take care of "translating" the messages for each technology.

4. Enabling Media Independent Handover

One of the key objectives of this work was the close integration of Mobility and QoS signalling for the various technologies. One of the issues, specific to the cellular air interface is the fact that it is conceptually very different from the 802.x access, in the sense that it is a connection-oriented technology and not a shared medium, and that it has full awareness and impact of the QoS.

The mobility was somehow the easiest part of the work as it is inline with the objective of the standard to detect, prepare and execute a handover. The selected architecture, as depicted in Figure 2, is a combination of the general MIH Reference Model and of the generic abstract architecture described in section 2.1.

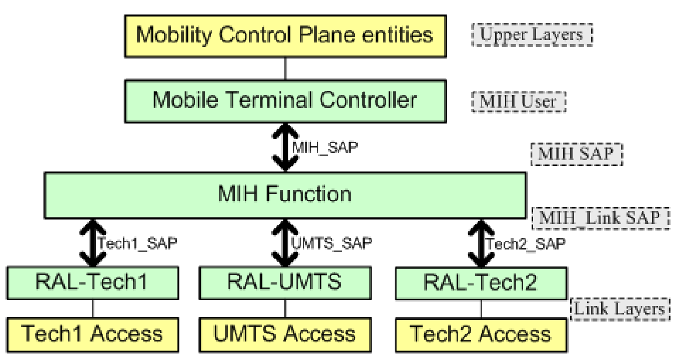

Figure 2: MIH-enabled architecture

The RAL-UMTS, derived from the entity implemented in the initial phase, maps the service primitives from the MIHF onto primitives to the inter-working middleware of the experimental platform and triggers directly the corresponding air interface procedures. This behaviour is different from the 802.21 standard, which monitors the 3GPP Session Management protocol (SM), rather than trigger the Mobility Management protocol (MM). The implemented UMTS-SAP currently supports two types of Media Independent Services: the Event Service and the Command Service.

A handover can be divided into two steps: the preparation, or trigger, and the execution. For the preparation, the Mobility Control Plane entities need to be aware of the existing network conditions. The measurements taken in the Access Stratum by the RRC, such as the signal level, the interference level, the path loss, are directly uploaded to the RAL which smoothes them out, analyses their variations and generates reports as Events to the MIHF and its users. As an UMTS PoA does not own a MAC address, these measurements are associated with the UMTS BS Cell_id. Such events are: Link_Parameters_Report when there is a sudden change of one of the parameters, Link_Going_Down or Link_Down when the signal quality drops below a certain threshold or the attachment is lost. The RAL is also able to report a Link_Up when the RRC has been able to successfully monitor the System Information Broadcast (SIB), camp on a suitable cell and successfully attach to this cell. Because both NIHO and MIHO are considered, the measurements can be read and uploaded at the MT level or at the network level, in the BS.

The Command Service is closely related to the Interface Selection process. The upper layers can request specific measurements, control the scanning of the Base Stations, or ask for some Link Actions such as Link Power Up or Link Power down operation of an interface. Whenever a Mobile Terminal handovers to the UMTS access network, the interface is activated by a "Link Action: Link Power Up" primitive. This triggers the network attachment of the UMTS interface to the Access Router and the establishment of an IP route towards the MT. The RRC Connection Establishment procedure is executed in the Access Stratum. When the MT has to move out of the UMTS, a deactivation command (Link Action: Link Low Power) is received. This cleans out all the data traffic contexts and, in our case, even detaches the interface from the network with a RRC Connection Release procedure. Afterwards, the Access Stratum continues to monitor the SIB and remains able to report measurements on request. Here, the UMTS interface is controlled dynamically, with more flexibility than what is planned by the current 802.21 standard, saving energy power resources in the terminal and making easier the execution of subsequent handovers over that interface. Even though it has not been selected by the 3GPP for Release 8, this is typically what could be expected from an interface compliant with the LTE architecture, which runs Mobile IP as a global mobility protocol to or from a non-3GPP access and so requires triggers and flexibility from the cellular access.

5. Enabling Media Independent Quality of Service

Since the UMTS is a connection-oriented technology, it is mandatory that some QoS resources be allocated in order to enable the transfer of the user data traffic. In the UMTS terminology, this is known as PDP Context Activation. The support of QoS in 802.21 considers the guarantee of service continuity during the handover, taking into account parameters such as the throughput or the Class of Service for example, but it does not consider the actual allocation of QoS resources during the handover through the use of 802.21 primitives. As described in [6], the QoS support is performed at the Layer 3 level by QoS Decision Points, centralized, and QoS Enforcement Points, located in the Access Routers. An abstract interface, close to the 802.21 architecture, has been designed to transfer requirements from the enforcement points to the Link Layer entities. It is very similar to Figure 2, but here, the QoS Decision Points and Enforcement Points play the role of upper layers. The L2 QoS Controller (L2QoSC) module, an MIH User, bridges the gap between the L3 and L2 QoS subsystems. It keeps track of the location (current PoA) of the MTs within an access network, knows the MIHF identifiers for all the PoAs and MTs, and is able to generate any number of MIH QoS reservation primitives for each L3 QoS request received from the upper layers. This extension of the MIH architecture allows a joint interaction between the mobility and the QoS support in the sense that the allocation of the data radio channels is performed during the handover execution phase.

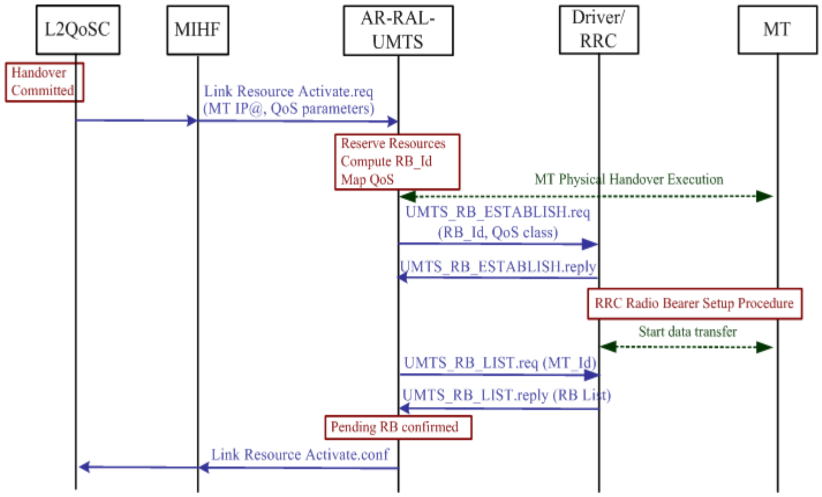

Figure 3: Activation of UMTS QoS resources

When the MT commits its handover to the UMTS network, the RAL in the AR receives a Link Resource Activate command, carrying the QoS parameters, such as the reserved bit rate or the Layer 3 QoS class identifier. The parameters are mapped onto one of the radio QoS classes available in the UMTS platform and the resource reservation is prepared. When the handover is executed and, as soon as the MT is attached to the new AR, the RAL triggers the physical allocation of the resources in the Access Stratum. This corresponds to a Radio Bearer Setup procedure directly in the air interface. Preparing the resource reservation ahead from the actual handover execution accelerates their establishment and improves the handover performance. When the MT moves away from the UMTS access, a Link Resource Deactivation, identifying the traffic flows that have been moved, is requested. This is relayed as a Radio Bearer Release in the air interface, but this action is less critical in terms of execution delay since the traffic flow has already been transferred to the new interface. It is thus requested only when the handover is complete.

Since this framework is very flexible, it has also been used for the establishment and release of MBMS (Multicast/Broadcast Multimedia Service) point-to-multipoint radio channels [7]. It is mandatory to establish them dynamically and not waste radio resources when no MT in the cell is interested in joining the multicast group. The procedure is identical to that of the point-to-point radio resources, except that a specific identifier in the MIH command indicates that a multicast resource is concerned. The received QoS parameters are available for the downlink direction only and mapped onto one of the specific MBMS QoS classes. Notification is also very important in the UMTS platform, as it starts the actual multicast flow reception in the MT. For that, we have created two new Command Service primitives, Link Multicast Join and Link Multicast Leave, carrying the multicast flow identifier together with the MT information. This study on multicast resources has been used as one of the basis for the 802.21b revision of the standard.

6. Executing Seamless Handovers with UMTS

This work has been applied to a road scenario use case where the passenger's own terminal is connected to WLAN in front of the university. He starts consuming an entertainment video. As the car moves out of the campus, the terminal handovers to DVB with UMTS as return channel, the handover being triggered by the decreasing signal strength of the WLAN. After a while, some personal preference settings related to the DVB rate fires some rules, the terminal drops the DVB connection and continues on UMTS only. Suddenly, due to an accident, the UMTS network gets overloaded and the network orders the terminal to handover to WLAN with WiMAX as backhaul. As the car is still in movement, the WLAN coverage is rapidly lost and the MT handovers to the next WLAN because UMTS is still not available. This sequence of heterogeneous handovers has been successfully implemented, integrated and demonstrated in the final testbed. In terms of implementation, it was much easier to develop all the layers above the RAL and the MIHF, since they didn't have to take care of the technology specificities, such as the UMTS technical details and parameters. However, implementation has shown that particular attention should be brought to end-to-end system specifications, because the MIHF serves as an intermediary entity only and does not make any checking on the validity of the parameters transferred. The figures below show some of the measurements that were performed during the final tests. During these tests, a data packet stream was transferred at a rate of 384 Kbits/s, which is a typical rate for 3G systems. The performance parameters taken into account were the average delay, the packet loss, the jitter and the modification of the payload rate. When the UMTS is involved in the handover, the average handover delay is measured at around 6 seconds, with a non-significant disruption time. This result was expected as the scenario applies to inter-technology handovers with make-before-break capabilities, which means that the new network attachment occurs before the old one is broken. The handover delay starts from the trigger of the handover to its final completion, which involves several steps of signalling exchanges. For the same reason, we confirmed that the packet loss was null during the handovers.

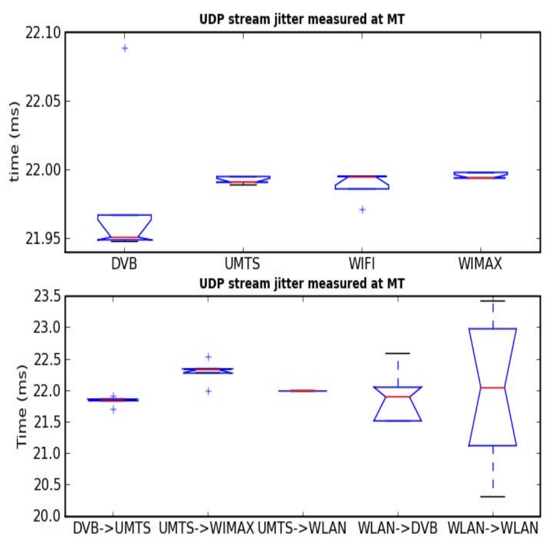

Figure 4: Jitter during sequence of handovers

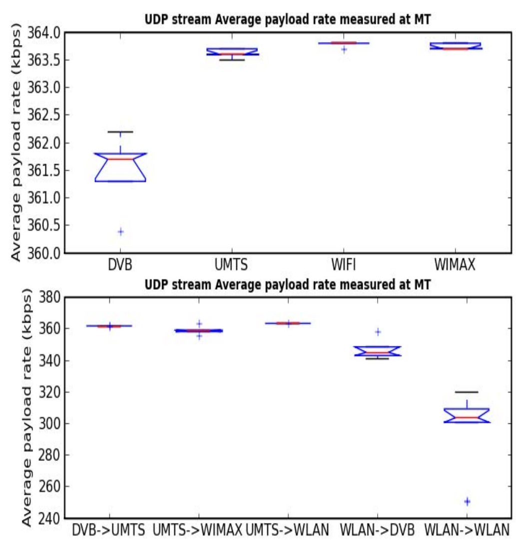

Figure 5: payload rate during sequence of handovers

Figure 4 shows the jitter measured at the MT during each handover, compared with the jitter obtained for each technology in a stable situation. The figures below show the global results for all the access technologies. However, the interest and discussion here is restricted to the scope of this paper, e.g. the UMTS interface. The diagram shows that the jitter is almost identical during the handover as it was in the stable situation, e.g. very close to 22 ms. We obtained a similar result when measuring the packet delay during the handover.

Figure 5 shows the average payload rate during steady traffic and then during the handovers. Again, we can observe here that the payload rate is kept at the same level during the handovers involving the UMTS interface. We can deduce that there is no impact from the dynamic radio resource reservation and establishment. Thanks to our integrated mobility and QoS architecture which allows preparing for the handover beforehand, all the radio resources are established as soon as the handover takes place. Another benefit of this study stands in the battery power saving. The attachment to the cellular network is performed only when needed, and so it is not necessary anymore to maintain the cellular interface active when other technologies, such as WLAN, are used, as planned in the 802.21. The outcome is that we achieved our objective of defining and implementing an architecture for true seamless heterogeneous mobility.

7. Conclusions

This paper presented an extension of the IEEE 802.21 standard for an experimental software radio platform used in cellular mode. This project targeted the integration of mobility with the QoS management and the seamless integration of broadcast. We have described here how the monitoring of the UMTS signal level and network could generate direct events in the technology-unaware upper layers, how MIH primitives triggered procedures in the cellular air interface for seamless handover and QoS resource allocation, including the control of the multicast channels part of the MBMS operation, and how the abstract IP-level parameters were mapped directly onto UMTS-specific parameters.

As a result of this study, we could execute successfully a sequence of seamless inter-technology handovers between three different types of access, involving cellular networks, with a low perturbation of the jitter or packet delay. Even though 802.21 has not been adopted by the recent decisions of the 3GPP, this research result could still be considered in a longer term future when multi-mode terminals will be able to accommodate seamlessly more than three different types of radios and access networks. The work presented here concentrated mostly on the Event and Command Services of the 802.21 standard. A direction for future activities is to complete this implementation with a study of how the UMTS can participate in the Media Independent Information Service, providing part of the network data broadcasted in each UMTS cell by the System Information Broadcast to the generic upper layer Control Plane entities.

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